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A SOLAR POWER GENERATION FOR SINGLE PHASE AC GRID USING BOOST DC – AC INVERTER WITH NON-LINEAR VARIABLE STRUCTURE CONTROL

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A single stage solar power generation with boost dc-ac inverter with non-linear variable structure control technique is proposed in this paper. A low output dc voltage of the solar pv array is boosted and inverted into a 220Vrms ac voltage at a fundamental frequency of 50Hz in a single stage circuit. A simple Non-Linear Variable Structure (NLVS) closed loop control technique is proposed to keep the output voltage constant barring various load conditions. Generally the double-loop control and feedback control techniques were used for controlling the output of the boost dc-ac inverter but it involves more complex control theory and not controls capacitor voltages respectively. Hence it cannot give instant response under inconsistent loads. Hence the proposed control scheme maintains constant output voltage and adopts with inconsistent load conditions. Therefore the proposed NLVS control scheme has more desirable features such as low cost and minimum number of switches. The Total Harmonic Distortion (THD) generated by the proposed configuration is quite reasonable. The complete system is modeled using MATLAB/SIMULINK.

Keywords: DC–AC power conversion, single stage solar power generation, Total Harmonic Distortion

1. Introduction

The decreasing of conventional energy sources, increasing of different pollutions and the ever increasing demand of the fossil fuels are driving the engineering society towards the investigation and the development of alternative energy sources which are less or zero pollution and eco-friendly [13]. Many renewable sources such as wind energy, biogas and solar are now well developed as the cost effective solution for many applications. Moreover the solar energy has become one of the most hopeful sources of energy as they are pollution less and fuel free. Beside this, solar energy is easy to adopt with existing power converters [2],[4],[6] and [19]. Hence, a power electronic interface is likely to be developed between solar system and the single phase utility grid or ac load, which mainly consists of MPPT Solar Charge controller, dc energy storage device and single

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stage boost DC-AC inverter are modeled by two current bidirectional buck boost converters [15]. Primarily the maximum energy from the solar photovoltaic array is extracted and stored in a dc energy storage device by MPPT solar charger, which was designed by boost converter and its output controlled by Maximum Power Point Tracking(MPPT) Technique[5],[22]. The Perturbation and Observation (P&O) algorithm is used in MPPT controller because P&O algorithm [5],[22] is most efficient than the other technique algorithms and it is more suitable for regulating the output voltage of the solar charger irrespective of solar radiation.

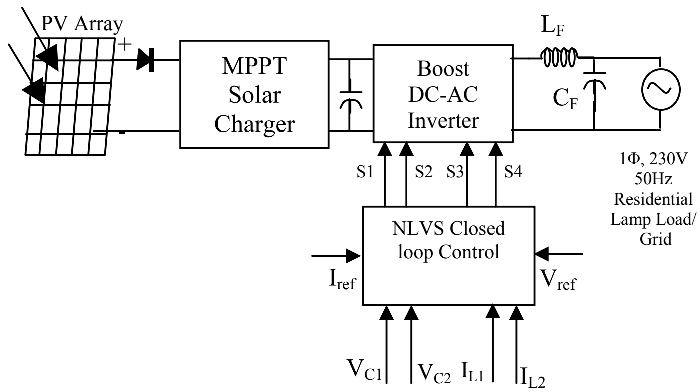


Fig. 1 The proposed solar energy conversion scheme

The proposed topology shown in Fig.1 used in this paper, maintains constant voltage under various loads. The double-loop control technique is used for controlling the output of the boost dc-ac inverter but it involves more complex control theory. Hence, it cannot give instant response in abrupt load changes. Also the voltage feedback closed loop control scheme is another method control technique which cannot control the load voltage under inconsistent loads. Hence, the proposed control scheme maintains constant the output voltage and adapts with inconsistent load conditions better than the double-loop control strategy and voltage feedback closed loop control technique.

2. Modeling of MPPT Solar Charger

The MPPT solar charge controller is designed by boost converter in which the output voltage is controlled by P&O algorithm based MPPT technique as in the Fig.2. A MOSFET is selected as a switch for Boost converter in which the average output current is less than the inductor current and also a high rms current is flowing through the capacitor. The output voltage of this boost converter is always greater than the input voltage and it is designed by the assumption of the following parameters.

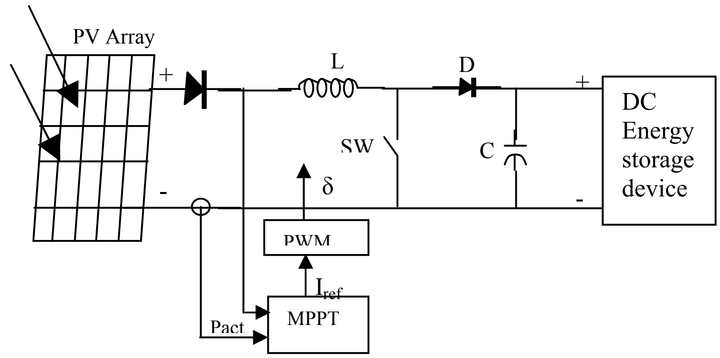


Fig. 2 Modeling of MPPT Solar Charger

1. The duty cycle (δ) of a boost Converter can be given as

2. $$\delta = 1 - \frac{V_{in}}{V_o} \quad (1)$$

V_{in} = input voltage of the Boost Converter which is equal to the output of the PV array; V_o = output voltage of the Boost Converter

2. The value of the inductor (L) can be given as

$$L = \frac{V_{PV}\delta}{2\Delta i_1 Fsw} \quad (2)$$

V_{PV} = output voltage from the PV array; Δi_1 = output ripple current; Fsw = switching frequency

3. The value of the output capacitor (C) can be formulated as

$$C = \frac{I_o\delta}{\Delta VFsw} \quad (3)$$

I_o = output current; ΔV = output ripple voltage

This Boost DC – DC converter is mainly responsible for the regulation of the output voltage and providing a constant voltage for charging the battery. PWM technique is adopted to regulate the output voltage of the Boost converter.

4. Single Stage Boost DC-AC Inverter

The proposed boost dc-ac inverter consists of two separate bidirectional buck-boost dc – dc converters [8,9] shown in Fig.3, which produces a dc- biased sine wave output so that each source only produces a unipolar voltage as in the Fig.4. The modulation on each converter is 180^0 out of phase with the other, which maximizes the voltage excursion across the load. The load is connected differentially across the two converters. DC bias voltage of each converter appears at each end of the load and differential dc voltage across the load is zero with respect to ground. The main advantage of this single stage boost dc-ac converter is the reduced number of switches and smooth sine wave of the output voltage. The proposed boost dc-ac inverter is shown in Fig.5

The output voltage of each converter is

$$V_1 = V_{dc} + V_m \sin\omega t \tag{4}$$

$$V_2 = V_{dc} - V_m \sin\omega t \tag{5}$$

Voltage across the load is $V_o = V_1 - V_2$

$$= 2V_m \sin\omega t \tag{6}$$

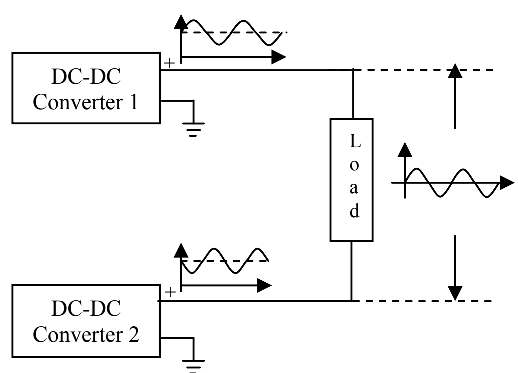


Fig. 3 Basic arrangement of two bidirectional dc-dc buck boost converters

The operation of boost dc-ac inverter can be explained by modes of operation and each converter operates under two modes such as:

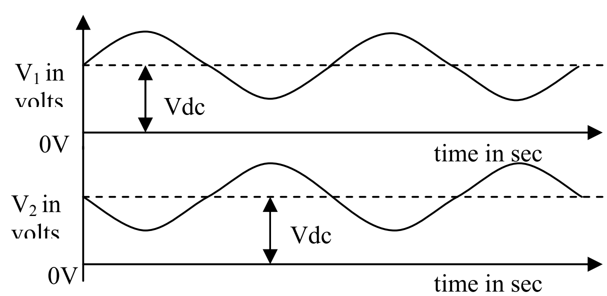


Fig. 4 output voltages of each dc-dc buck boost converters

Mode 1:

When the power switch S_1 is closed and S_2 is open as in the Fig.5, the current i_{L1} rises quite linearly, diode D_2 is reverse polarized, capacitor C_1 supplies energy to the output stage and voltage V_{C1} decreases.

Mode 2:

When the power switch S_1 is open and S_2 is closed as in the Fig.5, the supply voltage is V_{in}, the inductor current i_{L1} flows through capacitor C_1 and the load, the current i_{L1} decreases while capacitor C_1 recharged.

The conduction mode of the converter 1 is given by $\frac{V_{C1}}{Vs} = \frac{1}{1-\delta}$ and the conduction mode of the converter 2 is given by $\frac{V_{C2}}{Vs} = \frac{1}{\delta}$;

where δ is the duty cycle, V_{C1} is the voltage across the capacitor of the converter-1 and V_{C2} is the voltage across the capacitor of the converter-2, V_s is the input voltage to the single stage boost dc-ac inverter. Since the two converters are 180^0 out of phase, the output voltage is given by

$$V_0 = V_{C1} - V_{C2}\ ; \qquad = \frac{Vs}{1-D} - \frac{Vs}{D}\ ; \qquad \frac{V_0}{Vs} = \frac{2D-1}{(1-D)D} \tag{7}$$

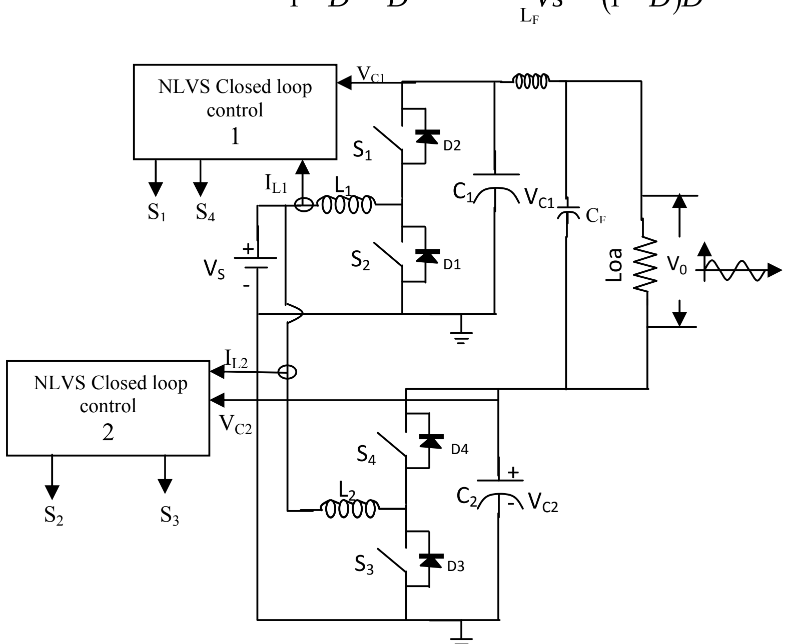
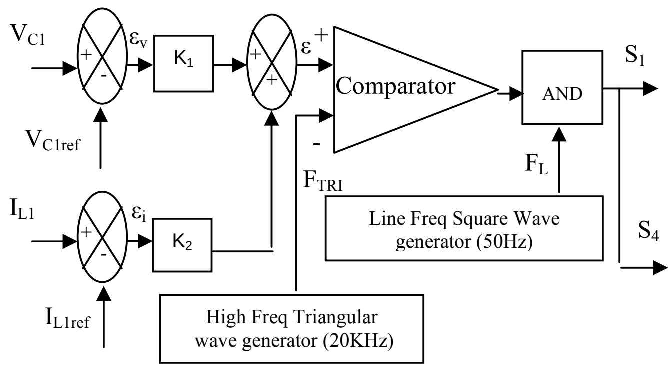


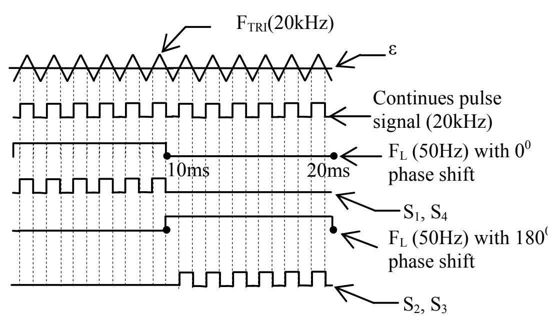
Fig. 5 proposed boost dc-ac inverter

5. Proposed Control Scheme for Single Stage Boost DC-AC Inverter

A simple non-linear variable structure closed loop control strategy is used for controlling the single stage boost dc-ac inverter shown in Fig.6(a). This method mainly compares error values of the capacitor voltage (V_{C1}) and inductor current (I_{L1}) of the boost dc-ac inverter with proper gains with the very high frequency triangular (F_{TRI}) signal. A continuous pulsatory signal produced by the comparator was modified using AND Gate to match with the grid frequency 50Hz as shown in Fig. 6(b). The main advantage of this closed loop control method is to keep the output voltage constant barring various transient conditions like abrupt load changes.



(a)



(b)

Fig. 6. (a) Proposed Non-Linear state variable structure closed loop control strategy for single stage boost dc-ac inverter ; (b) Generation of control signal for the switches of the Boost Inverter

The voltage across the capacitor (V_{C1}) and the inductor current (I_{L1}) of the converter 1 are adjusted separately with the proper gain values of K_1 and K_2 to get the proper duty cycle of the converter-1 and, as a result of comparator, we can get a continuous pulse signal. The very high frequency continuous pulsated signal is converted into fundamental frequency for getting proper output. This signal controls the switches S_1 and S_4 of the converter-1 and converter-2 respectively. The same technique is used to control switches S_2 and S_3 of the converter-1 and 2 respectively.

6. Simulation Model of Proposed System

The proposed single stage solar power generation with boost dc-ac inverter, in Fig. 7, was developed by MATLAB SIMULINK assuming the power switches, capacitor voltage and inductors current with internal resistance Ra are ideal. The parameters are:
Vin = 96 V, Vo = 325 sin(2n 50 Hz)t, Po = 40 W, L1, L2 = 750 µH each, C 1, C2 = 20 µF each, f_{SW} = 20 kHz at the duty ratio (D) of 0.67 .

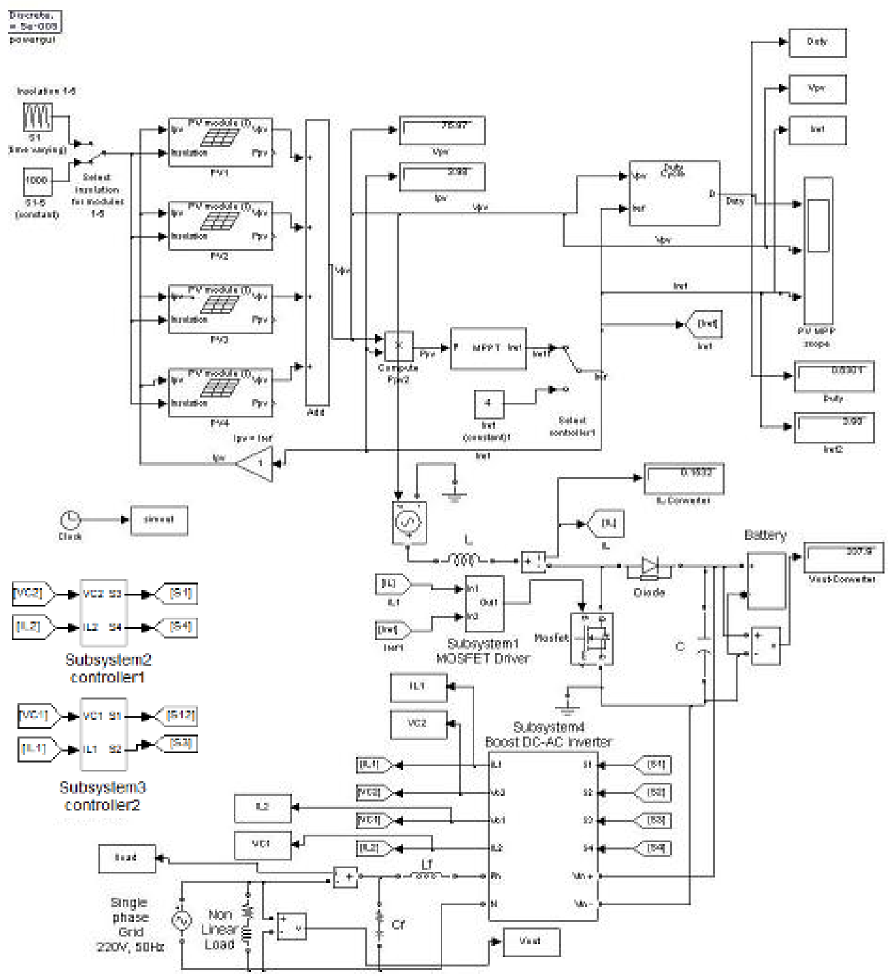
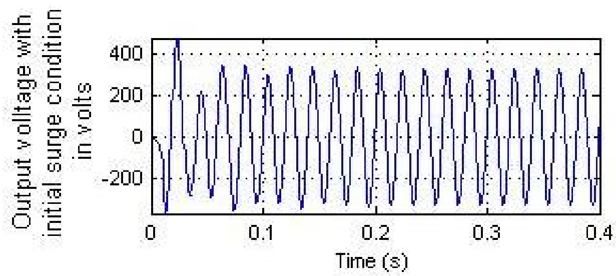
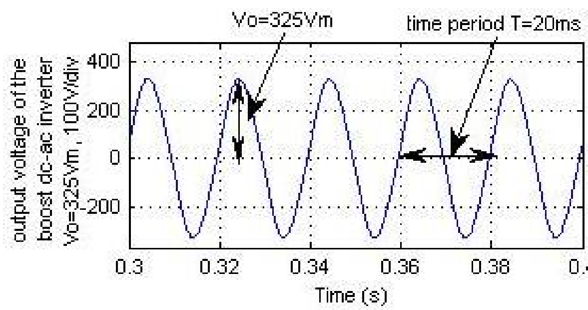


Fig. 7. MATLAB SIMULINK Model of Proposed single stage Solar Power Generation

6. Simulation Results

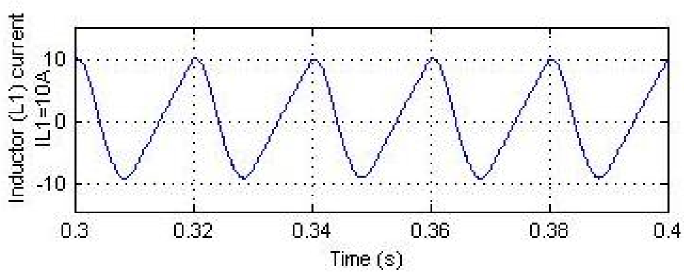


(a)

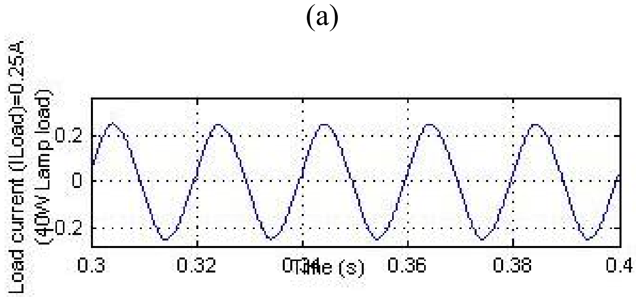


(b)

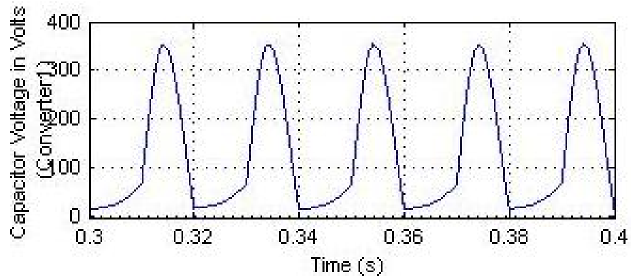
Fig. 8 (a). Single stage boost dc-ac inverter Output with initial surge voltage (Vo) in volts 100V/div, 0.1s/div; (b) single stage boost dc-ac inverter Output voltage (Vo) in volts 100V/div, 0.1s/div



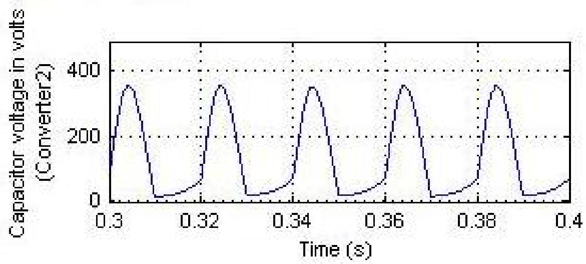
(a)



(b)

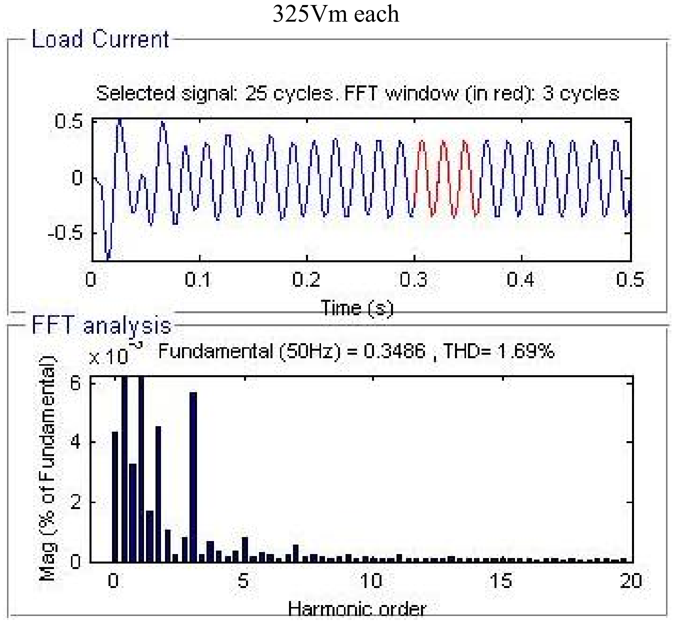


(c)

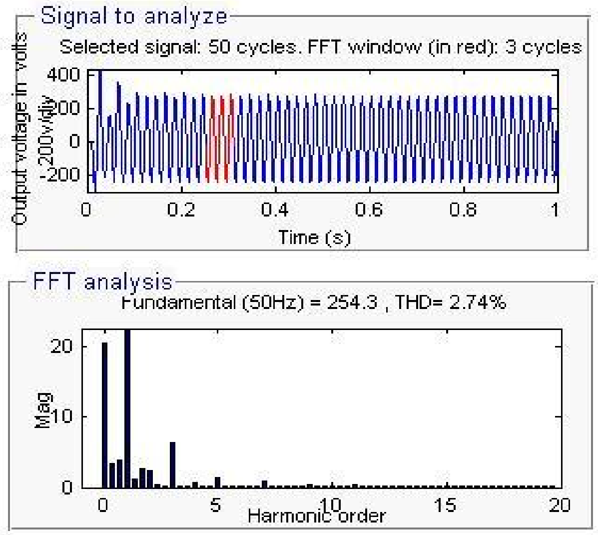


(d)

Fig. 9 (a). Inductor current of the boost dc-ac inverter (I_{L1}) 10A/div, 0.01s/div; (b) Load Current for 40watts lamp in Amps 0.2A/div, 0.01s/div; (c) &(d) Capacitors Voltage (V_{C1}&V_{C2}) in Volts 325Vm each



(a)



(b)

Fig.10. (a). Total Harmonic Distortion of the load current is 1.69% for the fundamental frequency; (b) Total Harmonic Distortion of boost inverter controlled by the non-linear variable structure closed loop control method for V_o is 2.74%

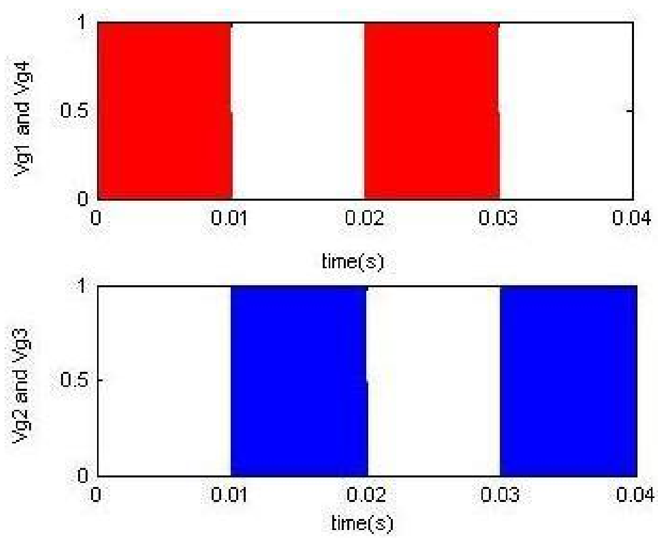


Fig.11 Control signals for switches as 1,2,3,& 4 of the single stage boost dc-ac inverter, generated by proposed simple NLVS closed loop control strategy

5. Results and Discussion

Fig. 8 shows the simulated results for the buck boost operation of the single stage boost dc-ac inverter for a non-linear load of 40 W. The peak value of instantaneous AC voltage is 325 volts. The Total Harmonic Distortion (THD) of V_O is lower than 2.8 % and it is shown in Fig. 10(b). In Fig. 9(a) is shown the inductor current i_{L1} of less than 10 A and very small current ripple. In Figs. 9 (c) and (d) one can see the capacitors voltages V_{C1} and V_{C2}; the maximum instantaneous value of the capacitor voltage is 350volts Figs. 10(a),(b) and (c) show the total harmonic distortion of the output voltage as 2.74% against the simulation result for a 40watts non-linear load and a total harmonic distortion in percentage of load current as 1.69% for fundamental frequency.

6. Conclusion

The proposed single phase topology of solar power generation for transferring the solar power to the utility grid is economical and efficient. This topology is a simple NLVS closed loop scheme which ensures the validity of the system since it compensates the load harmonics and the reactive power with the help of suitable series LC filter between the inverter and grid. Such solar power generation schemes show feasibility, effectiveness and operational simplicity. The low cost due to the minimum number of power devices used to execute the above scheme is an additional merit and also it satisfies the single phase grid parameters when it is synchronized.

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